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### Abstract

The Large Coil Program (LCP) has the objectives of obtaining and testing superconducting magnets of a size and in an environment that demonstrate feasibility of application for The Next Step (TNS). These magnets are to be in a toroidal array which may include from one to six magnets and are to be cooled by either pool boiling or forced convection of helium. The toroidal array will be housed in a large vacuum vessel measuring about 11 m in diameter and 11 m high. The magnets will be modified D-shaped coils, and will have a bore of 2.5 by 3.5 m.

The program objectives require a versatile and sophisticated liquid helium supply and cryogenic distribution system to meet the test requirements. The liquid helium supply system consists of a high pressure gas storage system, a 1050-kW, two-stage compressor, a refrigerator coldbox capable of delivering helium at two thermodynamic states, and a 19,000-liter helium storage dewar with the associated piping and controls. The refrigerator built by CTI is designed to supply the experimental load with either supercritical helium at temperatures to  $\sim 3.5$  K or as saturated liquid down to  $\sim 3.5$  K. The compressor system is an oil-flooded rotary screw unit capable of operating to 0.5-atm suction pressure. The first and second compression stage sizes are 300 kW and 750 kW, respectively, and they may be used either independently or in tandem. The features of the refrigerator-liquefier will be described in this paper. The features of the helium distribution system and cryogenic systems are described in a companion paper by C. G. Lawson and J. R. May.

### Introduction

The Large Coil Test Facility (LCTF) supplies an environment for testing superconducting magnets of a size and design that demonstrate feasibility of application for TNS. The test magnets are to be in a toroidal array which may include from one to six magnets and may be cooled by either pool boiling or forced convection of helium. The toroidal array will be housed in a vacuum vessel measuring about 11 m in diam and 11 m high. The magnets will be modified D-shaped coils and will have a bore of 2.5 by 3.5 m.

The test criteria require that each of the magnets be subjected to the abnormal heat loads which simulate pulsing of the poloidal field coils and to the absorption of nuclear radiation and fault conditions, including normalization of a complete one-half turn of the conductor while the test magnet is operating at 100% of design current. The remaining magnets, operating at 80% of design current, supply the background field. These requirements, in addition to the normal heat loads associated with heat leaks and with cooling the electric leads to the magnet, would require a maximum liquefaction capacity of about 330  $\ell$ /hr of liquid helium for lead cooling and a refrigeration requirement of approximately 950 W at 4 K. The breakdown of these heat loads is listed in Table 1.

### The General Flow Schematic

The helium liquefier-refrigerator for the LCTF has a rated capacity at 3.5 K of 866 W and 4.5 g/sec

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Table 1. Magnet heat loads at 100% of design current watts/magnet

	Pool Boiling (PB) 100% Test	Forced Flow (FF) 100% Test
Joints, Electric	56	56
Thermal leaks	20	20
Nuclear heating	128	128
Eddy current (pulse)	38	38
Pump power		300
Anomalies	3	3
Total	245	545
Assumed	250	550
Electric lead cooling helium requirement	55 $\ell$ /hr	55 $\ell$ /hr

(120  $\ell$ /hr) of liquid helium. This refrigerator will be used in conjunction with a high pressure gas storage system (17,000  $m^3$ ) and a storage dewar capable of holding 19,000 liters of LHe to supply helium for cooling the electric leads and magnets and for operation during the test program. The basic flow diagram is shown in Fig. 1. The helium storage tanks can receive gas from an outside source or provide helium gas to the compressor or the coldbox. The compressor can deliver helium gas to the coldbox or the high pressure storage system. The coldbox has two low temperature outlets and can deliver liquid helium to the storage dewar for future use or to the experiment. The helium is discharged through a JT valve before going to the storage vessel. The liquid in the storage dewar may be maintained at 1/2-atm to 2-atm absolute pressure while the compressor is operating through a line which vents to the coldbox vapor return line.

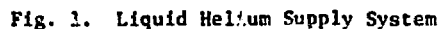
The helium delivered to the experiment can be routed through the bypass lines, so the final JT expansion will occur either before or after passing through the experiment if desired.

### The Refrigerator/Liquefier

The refrigerator coldbox was designed and built by CTI with a Sulzer gas lubricated expansion turbine. The refrigerator coldbox capabilities are shown in Table 2.

The coldbox gas lubricated turbine has a capacity of up to  $\sim 200$  g/sec and an expansion ratio near 5.5:1. The turbine, located between heat exchangers 3 and 4, receives about two thirds of the total helium at  $\sim 20$  K and 14 atm, and delivers at  $\sim 11$  K and 2.5 atm. Two-thirds of the helium flow from the turbine returns to the compressor through the first three regenerative heat exchangers. The remaining one-third continues down temperature to the last stage heat exchanger and the JT valve for liquefaction and refrigeration. The work extracted from the expansion engine is removed by a demineralized water stream.

There are four main heat exchangers in the coldbox. The first operates between room temperature and 77 K; the product helium is cooled by  $LN_2$ , the expansion engine discharge gas, and the return vapor flow. The second operates between 77 K and about 15 K. The third exchanger operates between 15 K and 11 K. The



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Table 2. Specifications for helium refrigerator system

<u>Overall</u>	
Supplier - CTI	
Suction pressure (compressor)	0.4 atm
Suction pressure (refrigerator)	0.5 atm
Liquefaction capacity (1.2 atm)	364 liters/hr (12.2) g/sec
Design capacity at 0.5-atm output	866 W, refrigeration and 4.5 g/sec to storage

Compressor

Manufacturer - Sullair Co.  
 Type - 2 stage rotary screw in series, oil flooded  
 Compressor ratio - ~ 36:1 overall  
 Capacity and range - 30 to 300 g/sec of helium gas (350 to 3500 scfm)  
 Power input - 300 kW, 1st stage; 750 kW, 2nd stage  
 Oil removal - 2 bulk oil separators, 2 coalescent mist separators, and a charcoal bed; also, special oil treatment for volatile removal

Coldbox

Manufacturer - CTI  
 Expansion engine - 1 gas lubricated, Sulzer, 200 g/sec helium flow  
 Internal calorimeter - for calibrating output and make-up and storage dewar  
 JT valves - 2 in parallel from coldbox; 1 on low pressure return for forced flow operation  
 Purifier - 2 parallel 20-K adsorbers  
 Precooling - LN<sub>2</sub> precooling, addition rapid cooldown LN<sub>2</sub> exchanger  
 Refrigeration flow rate - 80-90 g/sec output

Other

Liquid helium storage - up to 18,000 liters  
 Gaseous helium storage - 5700 m<sup>3</sup> of STP gas

Table 3. Duty factor for magnet testing with the available liquefier and refrigerator

	<u>Duty Factor</u>
1 coil: either PB <sup>a</sup> or FF <sup>b</sup>	1.0
3 coils: 1 FF test, 2 PB background	0.67
6 coils: 1 FF test, 1 FF, and 4 PB background	0.29
6 coils: 1 FF test, 3 FF, and 2 PB background	0.25

<sup>a</sup>Pool Boiling<sup>b</sup>Forced FlowConclusions

Accordingly, we conclude that the presently designed helium system is capable of carrying the LCTF if a duty factor of 0.25 is considered acceptable (running time 60 hours and recharging time 180 hours). If larger duty factors are desired with the six-coil tests, then an additional refrigeration capacity should be made available.

Reference

1. C. G. Lawson and J. R. May, "Helium Distribution System for the Large Coil Test Facility," Paper L-13 presented at this conference.

magnets. The helium distribution system within the LCTF for cooldown and steady operation will be described more fully in a companion paper<sup>1</sup> but will be briefly mentioned here to explain the base strategy.

Lead cooling will require up to 300 l/hr of LHe at 100% operating current. In addition, the refrigeration system demand for a 6-coil test with 1 force cooled test coil at 100% current and five background coils at 80% (4 pool boiling and 1 forced flow) requires 850 W at 4 K. This total requirement is clearly beyond the continuous capability of our liquefier-refrigerator. Accordingly, we are using storage dewars to supply helium to the leads and pool boilers while the refrigerator cools the force cooled magnets in a closed cycle with a cold pump. The helium from the electric leads will be returned to the gas storage tanks and the compressor. With this mode of operation, a test run series would last until the storage dewar was emptied, at which time all the magnet current would be reduced to 80%, the refrigerator would be switched to liquefier operation, and the storage dewars would be refilled.

Duty factors were estimated on the basis of the ratio of potential testing time to total low temperature operating time; the following results are listed in Table 3.